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# A Comparative Analysis of Advanced Methodologies to Improve the Acquisition of Information Technology for Optimal Risk Mitigation and Decision Support Systems to Avoid Cost and Schedule Overruns

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## Abstract

This study examines five advanced decision support methodologies, Lean Six Sigma (L6σ), Balanced Score Card (BSC), Integrated Risk Management (IRM), Knowledge Value Added (KVA), and Earned Value Management (EVM), in terms of how each can support the information technology (IT) acquisition process. In addition, the study provides guidance on when each methodology should be applied during the acquisition lifecycle of IT projects. This research includes an in-depth review of each methodology in the context of the acquisition lifecycle. All acquisition projects within the DoD must go through the acquisition lifecycle. While each acquisition project is unique, all must pass a series of common hurdles to succeed. Understanding how and when the methodologies can be applied to the acquisition of IT technologies is fundamental to the success of any IT acquisition. The study concludes with a set of recommendations for the use of each methodology in the acquisition lifecycle of IT projects.

## Problem Statement

A recurring issue at the U.S. Department of Defense (DoD) is that acquisitions of information technology (IT) have been fraught with schedule and cost overruns. High profile programs such as the Joint Strike Fighter, Coast Guard Deepwater program, Army Comanche, and the Navy A-12 demonstrate the need for improvement within the acquisition process. The problem is the current suite of management tools do not seem to adequately provide sufficient early warning and fidelity into the root causes of fiscal overruns in order to provide the program manager time to adequately respond to program issues. This is a problem because the capabilities promised to the warfighter are not provided in a timely manner and the over-budgeted resources used to provide the capabilities could be more efficiently allocated to other programs.

There are a number of analytical and decision support methods that can be used to improve the acquisitions of IT. This study will provide an approach that will aid practitioners in selecting the best approach for a given phase of the acquisition lifecycle for IT systems. The methodologies that were reviewed for this study included Lean Six Sigma (L6σ), Balanced Score Card (BSC), Integrated Risk Management (IRM: Risk Simulation, Parametric Forecast Models, Portfolio Optimization, Strategic Flexibility, Economic Business Case Modeling), Knowledge Value Added (KVA), and Earned Value Management (EVM).

### *Research Questions and Objectives*

The research questions are as follows:

1. When should the methodologies be used in the acquisition lifecycle to ensure successful acquisition of IT technologies?
2. How should the methodologies be used in the acquisition lifecycle to ensure successful acquisition of IT technologies?
3. What are the risks of using each of the methodologies for IT acquisitions?

The objective of the research was to provide a set of recommendations, based on comparison and contrast of the proposed methodologies, for when and how each method can be applied to improve the acquisitions lifecycle.

## Overview

The authors have conducted numerous research studies on the effectiveness of IT acquisitions in, for example, the areas of signal intelligence, ship building, and ship maintenance, to name a few.[1] The prior studies focused on the return on investment of IT, valuation of IT real options, and IT investment portfolio optimization. For example, the shipbuilding and maintenance studies demonstrated the value added of acquiring additive manufacturing (AM), laser scanning technology (LST), and collaborative product lifecycle management tools (CPLM). This prior research revealed the need to understand how the IT acquisition lifecycle should optimally be managed within the context of the DoD existing acquisition lifecycle frameworks.

The need for these IT technologies to improve productivity has been addressed in these prior studies using the KVA and IRM approach. For example, the KVA analysis of the "as-is" ship maintenance processes identified opportunities for improvement in process efficiencies. L6σ has been used for similar purposes in other studies. These methodologies identify opportunities for productivity improvement using IT. The strategic planning for the possible insertion of these technologies was further addressed in the current study by use of the BSC methodology. The standard means for managing and monitoring the progress of an IT acquisition in the DoD is generally approached using the EVM methodology.

Each methodology has its place in ensuring a successful acquisition of IT technologies. In addition to these methodologies, past acquisition studies (e.g., signal intelligence, ship maintenance and building) have utilized the IRM methodology to forecast the future value of acquiring given IT technologies as well as the risks involved in those acquisitions. The challenge for the current study was to identify and justify the application of each of the five methodologies in the acquisition lifecycle. Each has its strengths and weaknesses as prior research has pointed out, and each was investigated in terms of how they could support the entire IT acquisition lifecycle as well as their inherent limitations in doing so.

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[1] Most of these studies can be found on the Naval Postgraduate School Acquisitions Research Program website, https://my.nps.edu/web/acqnresearch.

This study will examine the potential use of the five methodologies to improve the chances for successful IT acquisitions. The methodologies were examined within the context of the routine (e.g., the 5000 series) acquisition lifecycle for IT. For the purposes of this study, the outputs from the Joint Capabilities Integration and Development System (JCIDS) and the Planning, Programming, and Budgeting Execution (PPBE) processes are presumed correct.

## Literature Review

There are other numerous management tools that might be applied to IT acquisitions (e.g., activity-based costing and TQM, to name two). However, a review of the literature supported the focus on the five main analytical methodologies identified for this study. Expanding the potential scope of this research to include other methodologies was deemed to add minimal value given that these five approaches are in current use in acquisitions management and research. It was also assumed that beginning with these five methodologies would provide a platform for inclusion of other approaches in future research. A review of each of the methodologies is provided in what follows.

### *Lean Six Sigma*[2]

Lean Six Sigma (L6σ) is a process performance-based methodology that focuses on improving efficiency, reducing costs, improving quality, and increasing process speed. It combines two kinds of process improvement techniques: lean and six sigma. Lean focuses on optimizing processes by eliminating waste while continuing to deliver valuable process outputs (GoLeanSixSigma, n.d.). Six Sigma is a method for reducing the number of defective process outputs with the goal of increasing efficiency as well as customer/user satisfaction. L6σ examines the details of the operations of processes in search of speed and cost improvements. L6σ consists of five phases, Define, Measure, Analyze, Improve, Control (DMAIC). First, the problem must be defined in order to limit the scope to an appropriate level. During measurement, analysts must quantify the problem to develop useful data for the following phase. Analyzing includes identifying the root cause of the problem in order to develop the necessary incremental steps to correct it. Improvement consists of implementing and verifying the incremental solution. Finally, control means maintaining the solution that was implemented during the improve phase.

L6σ requires certifications for its practitioners that range from Black Belt to White Belt. Each level or belt specifies the level of expertise a belt holder has in applying L6σ (MoreSteam, 2018). The belts, or experience levels, include the following:

- A Black Belt has expert knowledge and skills related to the DMAIC methodology, Lean methods, and team leadership.
- A Green Belt has strong knowledge and skills related to the DMAIC methodology and Lean methods, but typically does not have experience with advanced statistical tools such as design of experiments (DOE).
- A Yellow Belt is trained in the general Lean Six Sigma concepts and basic tools.

[2] This review of L6σ is taken from the following website: GoLeanSixSigma (2018). What is Lean Six Sigma? Retrieved from https://goleansixsigma.com/what-is-lean-six-sigma/.

- A project Champion is a high-ranking manager who will work with a Black Belt to ensure that barriers to project success are removed and the project team has the organizational support it needs to be effective.
- A White Belt has received a small amount (several hours) of awareness training.

This methodology has been used to incrementally improve the productivity of many DoD processes. It is also in current use as a means to help justify the future use of an IT system to improve process productivity within the DoD.

***Balanced Score Card***

The Balanced Score Card (BSC) is a strategic planning and management methodology developed by Kaplan and Norton (1996). The BSC includes financial metrics as well as nonfinancial performance measures, such as (1) leadership, (2) customer satisfaction, and (3) employee satisfaction, to achieve a balanced view of an organization's performance (Kaplan & Norton, 1996; also see Albert, 2002, and Niven, 2008). The BSC helps to strategically align an organization's actions to the vision and strategy of the organization, improve internal and external communications, and monitor organization performance against strategic goals.

The BSC typically uses four to five critical perspectives: (1) Organizational Capacity, (2) Customer/Stakeholder Satisfaction, (3) Financial Metrics, (4) Leadership Behavior, and (5) Internal Process Performance, to design a scorecard that reflects a company's vision and strategy. An organization can then develop strategic objectives, key performance indicators (KPIs), targets and initiatives relative to each of the perspectives, so that they can measure and monitor their progress based on the BSC (Balanced Scorecard Institute, n.d.).

Thereafter, the organization will need to convert the BSC into a strategy map so that it can be used to communicate and share with the rest of the organization. This strategy map will be a basic graphic that shows a logical, cause-and-effect connection among the critical perspectives. This is an important step that leads to high level vision and strategy statements that can be shared with the rest of the organization.

The organization should be able to measure the performance of its employees and management, based on the targets set in the BSC, as well as incentivize them with recognition and rewards. One of the roles of leadership is to ensure that the strategy map, based on the BSC, is clearly communicated and shared throughout the organization, so as to avoid strategic misalignments. The goal is to ensure accountability and ownership at the management level when the BSC has been executed, and employees should know what their performance targets are and what they need to do to achieve them. The organization should also conduct regular performance reviews to update and share the short-term results with its employees and management so that changes can be made based on a review of the progress toward a completed BSC. The goal of the BSC is to improve strategic alignment of all elements of the organization to ensure the BSC targets are the focus of the organization. A regular performance review also can help to motivate an underperforming area of the organization to improve its performance.

***Integrated Risk Management***

Integrated Risk Management (IRM) is a comprehensive methodology that is a forward-looking, risk-based decision support system incorporating various methods such as Monte Carlo Risk Simulation, Parametric Forecast Models, Portfolio Optimization, Strategic Flexibility, and Economic Business Case Modeling. Economic business cases using standard financial cash flows and cost estimates, as well as non-economic variables such as expected military value, strategic value, and other domain-specific SME metrics (e.g., Innovation Index, Conversion Capability, Ability to Meet Future Threats, Force Structure, Modernization and Technical Sophistication, Combat Readiness, Sustainability, Future Readiness to Meet Threats) can be incorporated. These metrics can be forecasted as well as risk-simulated to account for their uncertainties and modeled to determine their returns to acquisition cost (e.g., return on investment for innovation or return on sustainability). Capital investment and acquisition decisions within IT portfolios can then be tentatively made, subject to any budgetary, manpower, and schedule constraints.

In the U.S. military context, risk analysis, real options analysis, and portfolio optimization techniques are enablers of a new way of approaching the problems of estimating return on investment (ROI) and estimating the risk-value of various strategic real options. There are many new DoD requirements for using more advanced analytical techniques. For instance, the Clinger-Cohen Act of 1996 mandates the use of *portfolio management* for all federal agencies. The Government Accountability Office's (1997) *Assessing Risks and Returns: A Guide for Evaluating Federal Agencies' IT Investment Decision-Making* (Ver. 1) requires that IT investments apply ROI measures. DoD Directive 8115.01, issued October 2005, mandates the use of performance metrics based on outputs, with ROI analysis required for all current and planned IT investments. DoD Directive 8115.bb implements policy and assigns responsibilities for the management of DoD IT investments as portfolios within the DoD Enterprise, where they defined a portfolio to include outcome performance measures and an expected return on investment. The DoD (2017) Risk Management Guidance *Defense Acquisition Guidebook* requires that alternatives to the traditional cost estimation need to be considered because legacy cost models tend not to adequately address costs associated with information systems or the risks associated with them.

Projects can be broken down into their WBS and tasks, where these tasks can be combined in complex systems dynamic structures. The cost and schedule elements for each task can be modeled and risk simulated within the system to determine the total cost and schedule risk of a certain program. Program management (PM) is oftentimes integrated with IRM methods to provide a more holistic view in terms of acquisitions of IT programs.

### *Knowledge Value Added*

As the U.S. military is not in the business of making money, referring to revenues throughout this paper may appear to be a misnomer. For nonprofit organizations, especially in the military, we require the KVA methodology to provide the required "benefits" or "revenue" proxy estimates to run a true ROI analysis. ROI is a basic productivity ratio with revenue in the numerator and cost to generate the revenue in the denominator (i.e., ROI is revenue-cost/cost). KVA generates ROI estimates by developing a market comparable price per common unit of output multiplied by the number of outputs to achieve a total revenue estimate.

KVA is a methodology whose primary purpose is to describe all organizational outputs in common units. This provides a means to compare the current and potential future outputs of all assets (human, machine, information technology) regardless of the aggregated outputs produced. For example, the purpose of a military process may be to gather signal intelligence or plan for a ship alternation. KVA would describe the outputs of both processes in common units, thus making the ROI performance of any of the processes comparable.

KVA measures the value provided by human capital assets and IT assets by analyzing an organization, process or function at the process-level. It provides insights into each dollar of IT investment by monetizing the outputs of all assets, including intangible assets (e.g., such as that produced by IT and humans). By capturing the value of knowledge embedded in an organization's core processes (i.e., employees and IT), KVA identifies the actual cost and revenue of a process, product, or service. Because KVA identifies every process required to produce an aggregated output in terms of the historical prices and costs per common unit of output of those processes, unit costs and unit prices can be calculated. The methodology has been applied in 45 areas within the DoD, from flight scheduling applications to ship maintenance and modernization processes.

As a performance tool, the KVA methodology

- Compares all processes in terms of relative productivity
- Allocates revenues and costs to common units of output
- Measures value added by IT by the outputs it produces
- Relates outputs to cost of producing those outputs in common units

Based on the tenets of complexity theory, KVA assumes that humans and technology in organizations add value by taking inputs and changing them (measured in units of complexity) into outputs through core processes. The amount of change an asset within a process produces can be a measure of value or benefit. The following are the additional assumptions in KVA:

- Describing all process outputs in common units (e.g., using a knowledge metaphor for the descriptive language in terms of the time it takes an average employee to learn how to produce the outputs) allows historical revenue and cost data to be assigned to those processes historically.
- All outputs can be described in terms of the time required to learn how to produce them.
- Learning Time, a surrogate for procedural knowledge required to produce process outputs, is measured in common units of time. Consequently, Units of Learning Time = Common Units of Output.
- Common unit of output makes it possible to compare all outputs in terms of cost per unit as well as price per unit because revenue can now be assigned at the sub-organizational level or at a DoD process level.
- Once cost and revenue streams have been assigned to sub-organizational or DoD process outputs, normal accounting and financial performance and profitability metrics can be applied (Rodgers & Housel, 2006; Pavlou et. al., 2005; Housel & Kanevsky, 1995).

KVA differs from other nonprofit ROI models because it allows for revenue estimates, enabling the use of traditional accounting, financial performance, and profitability measures at the sub-organizational level. KVA can rank processes by the degree to which they add value to the organization or its outputs. This assists decision-makers in identifying how much processes add value. Value is quantified in two key metrics: Return-on-Knowledge (ROK: revenue/cost) and ROI (revenue-investment cost/investment cost). The KVA method has been applied to numerous military core processes across the services. It was originally developed to estimate the ROI on IT acquisitions in the telecommunications industry at the sub-corporate level and has been used for the past 17 years in the DoD, with emphasis on the Navy, to assess the potential value added by IT acquisitions to core DoD processes.

### *Earned Value Management*

Earned Value Management (EVM) provides cost and schedule metrics to track performance in accordance with an acquisition project plan during the developmental phase of the acquisition lifecycle after the Engineering Development contract is awarded. It uses a work breakdown structure (WBS) to try to measure the performance of a program based upon the amount of planned work that is done at any point in the program management baseline (PMB). EVM uses cost and schedule metrics that aid in performance trend analysis with a focus on identifying any budget and schedule deviations from the plan.

Given the propensity of IT acquisitions to be over budget and behind schedule, EVM metrics can help program managers identify and attempt to avoid overruns and schedule deviations. When variances in cost or schedule occur, EVM data can also be used to reforecast the budget and schedule with the focus of providing program managers with accurate performance information. It uses schedule and cost estimates to find the Planned Value (PV) of a given acquisition project. Cumulative PV provides the total value that should be achieved by a specified date (Reichel, 2006). The specific label for PV is Budget Cost for Work Scheduled (BCWS) within the DoD acquisitions community. Actual Cost (AC) is the accumulated accrued costs of labor and materials. The label for AC within the DoD acquisitions community is Actual Cost of Work Performed (ACWP). Earned Value (EV) measures the progress for a given plan. The DoD acquisitions label for EV is Budgeted Cost of Work Performed (BCWP; West, 2007). It may be possible to combine EVM with the IRM methodology to track IT acquisitions projects in a timelier manner, leading to fewer cost and schedule overruns.

Earned Value Management (EVM) is used by the DoD and industry for the planning and management of projects and programs. EVM is used in project management to locate emergent problems to allow the project team to take action as early as possible. EVM has been used for process improvements, but its strength is in providing a disciplined, structured, objective, and quantitative method to integrate performance, cost, and schedule objectives for tracking contract performance (DoD, 2015).

In order to utilize EVM, there are some variables and metrics that are calculated and compared to data contained in the project plan. The basis of EVM is an accurate plan with completion rates and budgeted costs (Reichel, 2006). This plan begins with the program work breakdown structure, in which the estimated cost and time are allocated to the PMB for every subordinate task as deemed appropriate by the management team and contract requirements. Once a solid plan is complete, the schedule and cost estimates will be used to find the *Planned Value (PV).* Cumulative PV will give the total value that should be achieved up to a specified date (Reichel, 2006). Period PV can be calculated for a specified period of time such as hour, day, week, and so forth, to get the amount of work that is planned over the duration selected. PV is called *Budget Cost for Work Scheduled (BCWS)* by the DoD when EVM is used to manage acquisitions. *Actual Cost (AC)* is the accumulated costs of labor and materials required to complete the project as they are accrued. The DoD refers to AC as *Actual Cost of Work Performed (ACWP)* for EVM in relation to acquisitions*. Earned Value (EV)* is a measure of progress against the plan. When referring to EVMs that are associated with DoD acquisitions, the EV term is *Budgeted Cost of Work Performed (BCWP)*.

There are several metrics and indexes that are computed using the previously computed variables discussed in the previous section. The primary metrics that are computed are variances that are related to cost and schedule.

1. *Cost Variance (CV)* is computed by subtracting AC from EV (West, 2007). A negative CV would represent a project that is over the planned budget.
2. *Cost Performance Index (CPI)* is computed by dividing EV by AC (West, 2007). As the metric moves towards zero, the higher the risk of going over the schedule. A CPI above one would indicate that the project is likely ahead of schedule.

3. *Schedule Variance (SV)* is computed by subtracting the PV from the EV (West, 2007). A negative SV would indicate a project that is behind the schedule.
4. *Schedule Performance Index (SPI)* is computed by dividing EV by AC (West, 2007). When the SPI moves lower than one towards zero, it indicates a potential cost or budget issue. An SPI above one would show that performance is likely exceeding the plan.

EVM is used to determine if a process is operating correctly with regards to costs and schedule. Using CV and SV, the process manager will be able to know if the process is not functioning as it was planned. As each step in the process is completed, the EV is computed and compared to the PV to determine the SV. A negative SV would indicate the process is running behind and action is needed to determine what is the problem. A positive number could indicate the process is over producing and creating pockets of inventory. Additionally, the CV can be computed to determine if a process is operating out of standard. A negative number could indicate over processing and exceeding standards, where a positive variance could indicate short cuts and possible defects. Regardless, any variance from the standard would only indicate that there may be an issue and the process owner needs to "go-look-go-see" and determine what is happening. The process manager would want to investigate the first step in a process that has a variance since that would be the strongest indicator of a possible issue. EVM would be most effective to monitor a stable process that has an established standard. It would not be very effective at determining if changing a process or automating a process would produce greater value. EVM is only focused on cost, and no metric or calculation is related to value, and it doesn't give insight into determining if a process's step should be automated.

## Research Methodology

A review of each of the methodologies was conducted as well as a high-level review of the current phases of the acquisition lifecycle (i.e., DoDI 5000 series). The methodologies were evaluated in terms of each major phase of the acquisition lifecycle to suggest how they might be used to enhance the likelihood of successful completion of the phase. Analysis included a review of how the general overall acquisition lifecycle approach might be modified to incorporate the benefits from the methodologies, including the original motivations for the IT acquisition per the problems/challenges identified prior to the beginning of the acquisition process. It was presumed that it was possible that the acquisition lifecycle should include a formal review of the need for the IT in the first place. It also was presumed that it was possible that the acquisition lifecycle should not end when the IT is actually acquired. We examined how the methodologies might be used to monitor the ongoing return on the investments in the IT.[3]

[3] The future version of this research, to be completed by October 1, 2019, will include a review of prior case studies, conducted by the authors, as well as those reported in various journals and ARP publications and reports. These case studies will provide a rich source of information for the final research report. The case studies included in the review have used a number of the methodologies (e.g., KVA, IRM, EVM) and may have benefited from using the other methodologies (i.e., BSC, L6σ). The review will be augmented by interviews of acquisition SMEs at NPS to test the assumptions of the principal authors concerning their assumptions about how and when these methodologies should be used in the acquisition lifecycle.

A review of the generic IT acquisition lifecycle and the mapping of this generic lifecycle to the existing DoD acquisitions framework is provided in what follows. The section following this review will provide a review of the benefits and challenges of using each of the five methodologies with final recommendations about how to use each within the generic acquisition lifecycle. The final section will include the future research and limitations of this study.

***Acquisition Lifecycle***

This study developed a basic framework for placing the five methodologies within the generic IT acquisition lifecycle in Table 1, Five Approaches: When to Apply in the Tech Investment Lifecycle. Table 1 can be mapped to the standard DoD Acquisition framework. Doing so allows a comparison of where the two general frameworks match up and provides some preliminary guidance for how the five methodologies might be used in the standard 5000 series acquisition framework.

**Table 1. Five Approaches: When to Apply in the Tech Investment Lifecycle**

| Pre-Investment | Strategic Goal Alignment | Implementation | Post Implementation |
|---|---|---|---|
| KVA (As-Is) | BSC (Align strategy with performance metrics) | EVM (Monitor cost and schedule, adjust as needed) | KVA (Monitor ROI, ROK) |
| **L6**(Id waste, value added) | IRM (Identify the strategic options for IT investments) | KVA (To-Be, ROI, ROK) | L6 ( Assess and monitor cost, waste reduction) |
| Other | Other | IRM (Use the project management tools within the IRM suite) | Other |

The Defense Acquisition lifecycle framework mirrors (i.e., Table 2, Aligning the Generic and 5000 Series Lifecycles) the generic technology investment acquisition lifecycle in that there exists a planning phase which includes activities consistent with pre-investment and strategic alignment, execution or implementation phase and an operations and sustainment phase, generally considered the post implementation phase of a program.

**Table 2. Aligning the Generic and 5000 Series Lifecycles**

| Pre-Materiel Solutions Analysis | Materiel Solutions Analysis | Technology Maturation and Risk Reduction | Engineering and Manufacturing Development | Production and Development | Operations and Support |
|---|---|---|---|---|---|
| -Strategic goal alignment<br>-Pre-investment | Pre-Investment | Pre-investment | Implementation | Implementation | Post-implementation |

The DoD defines these phases as the Material Solution Analysis phase, Technology Maturation and Risk Reduction phase, Engineering and Manufacturing Development phase, Production and Deployment, and the Operations and Sustainment phase. Figure 1. The 5000 Series Acquisition Lifecycle is a visual representation of these phases as they are defined in DoDI 5000.02 (OUSD[AT&L], 2017).

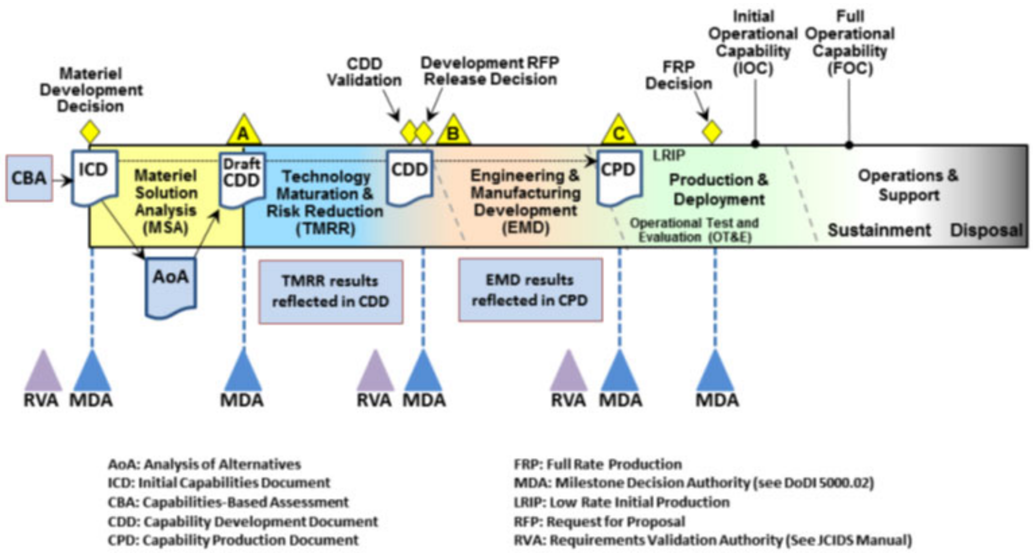


**Figure 1. The 5000 Series Acquisition Lifecycle**
(DoD, 2017)

***Materiel Solution Analysis Phase***

The Materiel Solution Analysis (MSA) Phase assesses potential solutions for a needed capability in an Initial Capabilities Document (ICD), which was developed during the defense requirements generation process known as the Joint Requirements Capability Determination System (JCIDS). The MSA phase is critical to program success and achieving materiel readiness because it is the first opportunity to influence systems supportability and affordability by balancing technology opportunities with operational and sustainment requirements. During this phase, various alternatives are analyzed to select the materiel solution and develop the Technology Development Strategy (TDS) which will be further assessed in the TMRR phase and eventually executed during EMD.

The MSA phase also includes identifying and evaluating affordable product support alternatives with their associated requirements to meet the operational requirements and associated risks. Consequently, in describing the desired performance to meet mission requirements, sustainment metrics are defined which will impact the overall system design strategy. One of the principle tasks that must be completed during this phase is the Analysis of Alternatives (AoA) suggesting that tools that offer robust tradeoff analysis might be better suited for this phase.

Significant events within the MSA and other phases of the acquisition lifecycle are listed in Table 3, Key Events Within the Phases of the 5000 Series. While this is not an all-inclusive list of events during each phase, important steps within a program's development are incorporated.

### *Technology Maturation and Risk Reduction Phase*

The Technology Maturation & Risk Reduction (TMRR) Phase is designed to reduce technology risk, engineering integration, lifecycle cost risk and to determine the appropriate set of technologies to be integrated into a full system. The objective of the TMRR phase is to reduce technical risk and develop a sufficient understanding of a solution in order to make sound business decisions on initiating a formal acquisition program in the Engineering, Manufacturing and Development (EMD) Phase. This phase lends itself well to management tools that allow the Program Manager to conduct technical and business process tradeoff analysis studies relative to cost and schedule.

**Table 3. Key Events Within the Phases of the 5000 Series**

| MSA | TMRR | EMD | P&D | O&S |
|---|---|---|---|---|
| Analysis of Alternatives | Preliminary Design Review | Complete detailed design | Low rate initial production | Lifecycle Sustainment Plan (LCSP) |
| Initial funding estimates | Capability Development Document | System-level Critical Design Review (CDR) | Initial Operational Test & Evaluation (IOT&E) | System Modifications |
| Technology Development Strategy | Competitive prototyping | Establish project baseline with Performance Measurement Baseline (PMB) | Full rate production decision | Sustainment |
| | Acquisition Program Baseline (APB) established | | Initial and Full Operational Capability (IOC and FOC) | Disposal |

### *Engineering and Manufacturing Development Phase*

The Engineering & Manufacturing Development (EMD) Phase is where a system is developed and designed before going into production. The EMD Phase is considered the formal start of any program and the point at which a development contract is awarded based upon a specific statement of work (SOW). The goal of this phase is to complete the development of a system or increment of capability and evaluate the system for technical maturity before proceeding into the Production and Deployment (PD) Phase. This is the phase in which cost and schedule variance models that help the PM to better understand technical issues is best employed since requirements are fundamentally solidified and represented in the SOW. If requirements are shown to be less than optimal or there are other mitigating issues during this phase that impact cost and schedule, then decision support tools to facilitate tradeoffs may be used to help the PM maintain the program baseline and deliver user defined capability.

### *Production and Deployment Phase and Operations and Sustainment Phase*

These phases are necessary for the program manager to ensure that the product being manufactured meets the operational effectiveness and suitability requirements for the user or customer. While the design is pretty well set at this point in the program, there may still be some trades that take place prior to the full rate production decision and fielding of the system. The program manager is less concerned with managing cost and schedule variance at this point since the contract types typically revert to a fixed price strategy. The biggest concern for the PM at this point is correcting any final deficiencies in the system and establishing a stable manufacturing and sustainment process.

The four generic phases listed in Table 1 align with the current DoD structure, as shown in Table 2. As the scope of this research is limited to the 5000 series, the pre-materiel solutions analysis column is for informational purposes only. The JCIDS process accomplishes strategic goal alignment, determining the necessary additions to the DoD's capabilities portfolio prior to the 5000 series. The Initial Capabilities Document (ICD) generated in the JCIDS process describes the high-level needs that the user requires, and these needs are assessed in the AoA process during the MSA phase. Within the scope of this paper, the DoD acquisition lifecycle and generic IT acquisition lifecycle begin with pre-investment during MSA.

If one discounts basic scheduling and cost management practices, the primary tools to monitor progress of an acquisition program during the MSA and EMD phases are EVM and the Risk Management Framework (RMF). Figure 2, Seven Steps to Risk Management Framework, shows the seven steps that comprise RMF, repeating in a cyclical pattern: prepare, categorize, select, implement, assess, authorize, and monitor.

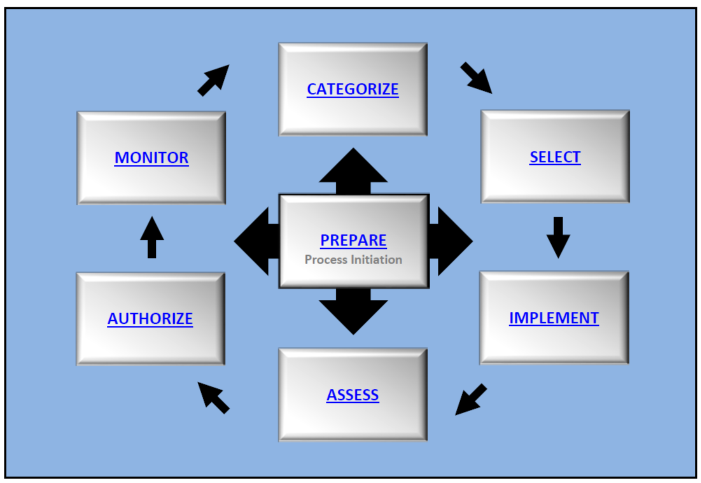


**Figure 2. Seven Steps to Risk Management Framework**
(Joint Task Force Transformation Initiative, 2018)

Preparation initiates the process, ensuring organizations are ready to execute RMF and giving context and priorities for managing risk (Joint Task Force Transformation Initiative, 2018). Categorization consists of organizing the system and the information used by the system based on an impact analysis (Joint Task Force Transformation Initiative, 2018). The risk manager then selects the appropriate security controls, tailoring them as necessary (Joint Task Force Transformation Initiative, 2018). The controls must then be implemented into the system and its operating environment before assessing the controls' effectiveness and authorizing the use of the information system (Joint Task Force Transformation Initiative, 2018). Finally, the manager must monitor the security controls on a continual basis, repeating the cycle as necessary when deficiencies are discovered (Joint Task Force Transformation Initiative, 2018). EMD is the first time program managers use EVM in an official capacity. The appropriate decision makers approved a schedule and budget for the program creating the Acquisition Program Baseline. Future progress is now measured against this benchmark. Even using these proven tools, cost and schedule overruns occur regularly, illustrating the need for a different approach.

The RMF is a broad analysis that covers multiple types of risk and is used throughout the entire lifecycle of a new development system. Implementing other tools into the process could help program managers better understand the risk involved at various decisions and points throughout the program. Within an acquisition there is an interdependence of risk. As the program progresses (and using the EVM methodology) and the ACWP increases, there are increasing levels of aggregation and abstraction of risk. For instance, to award an EMD contract, the technology involved must be at a Technology Readiness Level (TRL) of TRL 6, indicating the technology performed adequately in a relevant test environment (Assistant Secretary of Defense for Research and Engineering [ASD(R&E)], 2011). However, the technology is not yet completed and requires significant improvement before production. The current risk assessment program does not account for the possibility that this categorization is incorrect and may not lead to a fully operational system. As a result, program managers proceed with the assumption that the technology will continue development as planned. Any lack of progress will not become apparent until the ACWP begins to vary from the BCWP. It is often too late to make the appropriate corrections to the program in order to remain on budget by the time the discrepancy is discovered using EVM metrics.

Early risk management that focuses on the validity of the decision-making process using the RMF framework might introduce a higher level of understanding of the subordinate processes. For example, if at a particular milestone, the technology is not at the level of readiness it is being portrayed, then the consequences are x, y, and z. The results of each statement can be expressed in terms of time and money or, keeping with the already established EVM terminology, potential Cost Variance. A program manager can then assign a probability of success estimate to the state of the program which might drive a deeper understanding of the various interdependent program management processes.

Table 4, Methodologies Within the 5000 Series, shows when each methodology might be used in the 5000 series phases. What follows summarizes the alignment of the various program tools that can provide better insight into the lifecycle of a program. This table reflects that there are multiple tools for the various phases that should be used in concert and that certain tools are more appropriate for a particular phase than others. It is incumbent on the PM to use the tools appropriately in that they provide more information for a complex environment. The tools themselves do not provide the solutions to potential problems; they are simply indicators of underlying performance issues.

**Table 4. Methodologies Within the 5000 Series**

| Materiel Solutions Analysis | Technology Maturation and Risk Reduction | Engineering and Manufacturing Development | Production and Development | Operations and Support |
|---|---|---|---|---|
| BSC | IRM | EVM | EVM | KVA |
| IRM | KVA | IRM | IRM | L6σ |
| KVA | L6σ | KVA | KVA | |
| L6σ | | | | |

Understanding the extent to which a particular tool might provide greater insight into program performance across the lifecycle, one should consider the level of analysis required and the viability of a particular tool to provide sufficient insight at that level of analysis. Three levels of analysis were considered for this initial survey: Organizational, Business Process, and Task Analysis.

It is clear from Table 5 that a variety of tools are required across the lifecycle in order for the PM to gain a more robust view of the program performance. The selection of the tool will depend on the particular focus and time horizon with which the tool is able to provide relevant information about the program. Simply relying on one tool will not allow the PM to adequately manage the program. Planning for the type and depth of the management tool is started early in the lifecycle and should be part of the overall acquisition strategy. Additionally, selecting contractors that are able to implement and manage these tools is critical in the decision-making process.

**Table 5. Management Tool Selection Criteria Based Upon Level of Analysis, Focus of Analysis, and Acquisition Phase**

| Level of Analysis | Focus of Analysis | Acquisition Phase |
|---|---|---|
| Organization | -Strategic competitive advantages: BSC, IRM<br>-Value=Revenue: BSC, IRM strategic options | MSA/TMRR/P&D/O&S |
| Business Process | -Cost savings: L6σ, EVM, BSC, IRM<br>-Schedule: EVM<br>Value: KVA outputs | MSA/TMRR/P&D/O&S |
| Task Analysis | -Cost savings: L6σ, IRM<br>-Value=Cost+schedule cycle time: L6σ, BSC | TMRR/EMD/P&D |

The BSC is an excellent tool when viewing a system holistically. It provides a way for managers to examine a project from a systems thinking approach. It may be most useful when strategizing about the potential use of an IT acquisition and how it might fit into the DoD's higher-level strategic goals prior to developing a requirements document. The statements derived from the BSC for general dissemination among all levels of the organizational structure must be translated into a simpler form presented in a set of objectives and targets that are clear for all levels within the organization. It is also important to understand that leadership is central to ensuring any IT acquisition will support the organization's overall strategy enumerated in the BSC. This is true in the DoD as well as in any organization's implementation of a BSC (Llach et al., 2017). Without leadership support and guidance, the BSC is unlikely to succeed, and the organization will not be able to generate acceptable returns on its IT investments.

**Table 6. Benefits and Challenges of the Five Methodologies**

| | Extensible, quantitative value measurement | Time to Perform | Cost | Bottleneck Analysis |
|---|---|---|---|---|
| BSC | No, subjective measurement (revenue is exception) | 3-6 months (depends on level of analysis) | Accounting based financial metrics only | None |
| EVM | No, cost measurement only | 5+ months set up time (depends on requirements) | Cost of resources and time | No, linear tracking only |
| L6σ | No, nominal value only | 3+ months (depends on level of process complexity) | Activity Based Costing approach | Direct bottleneck analysis |
| KVA | Yes | 2 days – 1 month (depends on level of analysis) | Common units of cost | Elapsed time versus work time |
| IRM | Yes, KVA | 3-6 months (Relatively quick once initial steps completed) | Cost accounting and KVA cost metrics | Monte Carlo simulation |

The use of the BSC can result in a cursory review of key performance indicators (KPI) during the traditional acquisitions lifecycle management process. The BSC also avoids over relying on financial KPIs by viewing the effects of each of the KPIs on the other parts of the scorecard. While financial KPIs are reviewed with the BSC, the other segments are separated from a purely financial analysis, allowing managers to use their judgement in determining how the proposed solution will affect the scorecard as a whole. The problem is that without a quantifiable common units performance metric that allows the practitioner to determine the relative value between the different scorecards, it is difficult to determine which course of action would be optimal. There is no performance ratio that tells the manager that by performing a given action the financial KPIs will improve by a given amount, the stakeholder engagement will decrease by this amount, and the internal process will change by this amount. Instead, it is more of a conceptual thought exercise to ensure managers consider the effects of their decisions on the entire range of KPIs. Because of this, the BSC works best during the strategic goal alignment phase of the generic IT acquisition lifecycle and the pre-MSA portion of the DoD acquisition lifecycle. The MSA phase also includes aligning the stated requirements with the possible solutions to the capability gap during the AoA. An all-inclusive view of the effects the various IT solutions that are being considered will assist in the selection of the most appropriate option to continue towards acquisition. The BSC is recommended for implementation during the MSA phase.

EVM provides users with an easily understandable report of a project's advancement towards completion. Comparing the BCWP and the ACWP gives a clear view of how a system is progressing within the anticipated budget. The metrics used for cost and time are also clearly delineated. This delineation allows managers to compare the performance at different locations throughout the project, which can assist in determining where a project has changed trajectories. There are numerous challenges when using EVM as well. While cost is measured and tracked regularly, the value of the project is not monitored as closely. Despite the name, the amount of work performed does not tell a manager the actual quantifiable value (in a common units measurement) the project has incurred at a given point. There is no quantifiable measure of value within the methodology. The only quantitative measures of performance are measures of cost and time.

The ACWP assumes the outputs from all work were perfect upon completion. If there are issues with the results from earlier efforts, they must be reworked, changing the ACWP calculation. As in the earlier example, if the technology does not improve as expected because the TRL was not accurately portrayed, a program manager will believe the project is on schedule despite the 'earned value' lagging behind what the numbers are projecting. Additionally, and in some instances because of this assumption, EVM outputs are not timely. Conducting an accurate analysis of a program is time consuming and does not provide useful predictive information. By the time EVM alerts a program manager to a variance, the variance has already occurred. All corrections are reactive to bring the ACWP back to the baseline, which has proven to be a nearly impossible task in practice. EVM will only be effective when the baseline plan is well researched and accurate. Otherwise, the ACWP is compared against flawed data. EVM does provide valuable information to project managers during the EMD phase but should be supplemented with some of the other methodologies: L6σ, KVA, IRM throughout the project management cycle. EVM is recommend most for use during the EMD and P&D phases.

Successfully implementing L6σ into a process will lower the cost of the project by reducing the variation in a product run and the waste associated with its production. When additional steps or unnecessary waste is reduced, additional resources are now available for use in other processes. In identifying a bottleneck, L6σ can address multiple problems simultaneously depending on how the project is defined. By creating improvement in one area and freeing resources, other areas may benefit from an improved process work flow. L6σ can be costly to implement. The analysis requires a great deal of time and information to develop meaningful understanding of any problems. L6σ's definition of value is at the nominal scale level: an item either adds value to a project or it does not. Reality is not often as black or white. There are required steps that must be conducted that do not necessarily add value to a product from the user's standpoint. For instance, accounting departments do not attempt to directly add value to a final product, but any organization recognizes the need for accounting, suggesting the accounting department does add value. L6σ is time consuming when applied on a large scale, as would be the case in a DoD acquisition. Defining the problem and determining appropriate measurements in a step by step manner is a major undertaking. Contractors can gain much of the benefit from L6σ when performing their internal processes during the TMRR and EMD phases. However, acquisition professionals should use L6σ during the MSA and TMRR phases to ensure the project is defined and measured appropriately. L6σ should also be employed during the O&S phase to ensure the LCSP is carried out as efficiently as possible.

The greatest benefit from KVA is a quantifiable (common units) value metric which can be compared across various aspects of a project (Housel & Bell, 2001). If the value of an intermediate step is quantified, managers can compare the outputs of a component instead of simply the effort measured by time and cost that were inputs. KVA provides a value measurement for both tangible and intangible assets, making it especially well-suited for use with IT. A KVA analysis can be accomplished in a relatively short period of time in comparison with the other methodologies. A quick, rough-cut KVA analysis can provide rapid guidance for the project before sinking valuable time and resources into a more comprehensive examination. KVA is primarily a measurement tool that provides performance information to decision makers. It is not a system that will drive an acquisition project towards the goal on its own. As in the other methodologies mentioned thus far, KVA has limited value in making predictions for future value, focusing instead on the current value of systems in development. There must be another methodology employed with KVA to ensure a project's success. Due to its ability to provide a quantitative, comparable value metric, KVA is recommended for use during all phases of the 5000 series.

IRM provides a foundation to incorporate the risk associated with a decision into a quantitative decision process. IRM's core premise maintains there is a probability for success and failure with every decision option during a project's lifecycle. Using statistical simulations, real options, and optimization will improve the quality of information a program manager has to determine the course of a project. Real options analysis can be used to frame strategies to mitigate risk, to value and find the optimal strategic pathway to pursue, and to generate options to enhance the value of the project while managing risks. IRM's drawback is that the analytical methods can sometimes be difficult to master. But with the requisite knowledge and training, coupled with the correct tools, the IRM methodology can provide a plethora of value-added information for making strategic and tactical decisions under uncertainty. The IRM methodology should be employed during the MSA, TMRR, EMD, and P&D phases.

### *Limitations and Future Research*[4]

This research only examined the 5000 series acquisition lifecycle. It is probable that both the JCIDS and PPBE processes could benefit from the calculated implementation of some or all of the methodologies discussed. Improving one component of the Defense Acquisition Decision Support System will likely improve the outputs of the other two systems. Additional research into creating a quantifiable measure of risk will provide beneficial information that allows decision makers to understand the probability of success for subcomponents within a project.

Future research in how the five methodologies might be useful for other areas of investment in IT and DoD acquisitions of IT might prove useful in extending the current research study. The proposed five methodologies may be useful for researchers who are also interested in focusing on the following topics of acquisition research interest:

- Innovative Contracting Strategies—contracting at the speed of relevance (BSC, IRM)
- Breaking down silos, enterprise management (L6σ, KVA)
- Rapid Acquisition and Decision Support (IRM, KVA)
- Effects of Risk-Tolerant and Risk-Averse Behavior on Cost, Schedule, and Performance (IRM, EVM)
- The Role of Innovation in Improving Defense Acquisition Outcomes (BSC, IRM, EVM)
- Applying Model-Based Systems Engineering to Defense Acquisition (IRM, KVA)
- Augmenting the Acquisition Decision Processes with Data Analytics (IRM)

[4] Given that the case studies of IT technology acquisitions exist in various existing data sources and written case studies, there is very little risk associated compared to the normal generation of new data sets that were required in the prior studies performed by the authors for the ARP. Access to acquisition subject matter experts (SMEs) at NPS reduced the risk associated in seeking other SMEs to discuss IT acquisitions and the use of the methodologies within the IT acquisition lifecycle.

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